OLIVINE CRYSTALS AND THE PETROGENESIS OF THE APOLLO 15 OLIVINE-NORMATIVE MARE BASALTS: 1. PETROGRAPHY. K. Herrell[1], K. Nakamura[1], G. Ryder[1], and B. Schuraytz [1,2]. [1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058-1113, [2]now at Planetary Science Branch, SN4, NASA Johnson Space Center, Houston, TX 77058.

Our chemical analyses of a suite of 25 Apollo 15 olivine-normative mare basalt samples, using splits of 4 to 5 g, validated previous conclusions that the suite chemistry is controlled by olivine [1-8]. However, the simplicity of the chemical model is not matched by a corresponding simplicity of petrographic features, such as can be interpreted as a sequence that includes cumulate olivines and successive flow fractionates [7-8]. At the Apollo 12 landing site, a group of olivine-normative mare basalts has the characteristics expected of a single thick flow in which olivine crystallized and sank [9,10]. However, for the Apollo 15 olivine-normative mare basalts the relationships are not as easily explained: there are no glassy samples and there is a lack of olivine as large phenocrysts. There is a wide variety of textures and grain-sizes, in contrast with typical terrestrial basalt flows, in which variation within a flow appears to be much less e.g. [11,12]. The Apollo 15 olivine-normative mare basalts range from fine-grained (pyroxene and plagioclase less than 200 μm) to coarse-grained (pyroxene and plagioclase more than 2 mm). Vesicular samples occur for both coarse and fine grain sizes. The question then is where the olivine separation that controls the chemistry of the Apollo 15 olivine-normative mare basalts took place, and how the samples came to crystallize to what they are now.

In the present study (not yet complete) we are evaluating the characteristics of the olivine itself in an effort to constrain the crystallization and subsolidus histories of each sample. Variations in the sizes, shapes, abundance, and mineral chemistry of olivine can shed light on how and where the olivines crystallized. With consideration of other rock characteristics, such as the grain size and shape of other minerals, in particular pyroxene and plagioclase, we can further understand the cooling histories and recognize how the process of olivine separation was physically achieved. A specific goal is to assess if the olivine separation took place in surface flows or in subsurface magma chambers, and whether each sample, or small subgroups of samples with similar compositions, represent separate intrusions and flows. In this abstract we discuss some of the petrographic observations; in an accompanying abstract (Nakamura et al.) we discuss some aspects of the compositional variation of the olivines.

Samples and methods: Thin sections of all 25 samples analyzed for chemical composition have been inspected. One sample, 15256, is an impact melt and is not considered further. For each sample we made a large scale (~70x) photomosaic for mapping purposes and measuring grain sizes. Records were made of olivine characteristics ranging from size and shape to inclusion types. The mosaics were re-photographed and scanned to obtain digital images. These were used to graphically map olivines and total rock area to derive the modal % olivine in a sample, using computer image processing techniques. Only the larger more magnesian olivines that may have some bearing on fractionation were mapped in this way; the small interstitial iron-rich olivines were not. Groundmass olivine was in any case found to be only a small part of the total olivine abundance. Such olivine abundances have so far been acquired for about half the samples. We are also using these mosaics to get a general measure and comparison of the grain-sizes of the samples using pyroxene and plagioclase dimensions. The relative grain size of the samples used in Fig. 1 is from plagioclase dimension, which we are presently better quantifying.

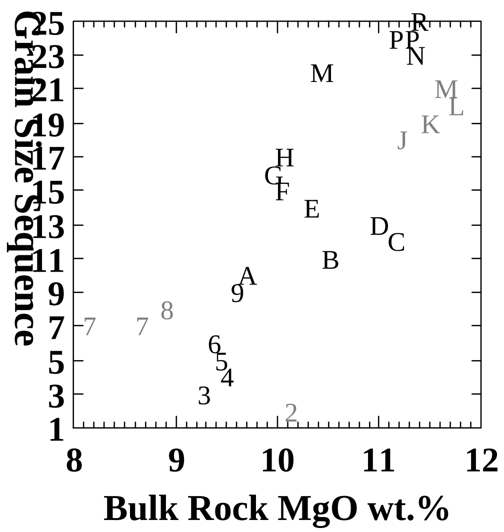
To obtain more information on the size and distribution of olivines, we also inspected some large, mainly planar sawn surfaces of 7 samples in the Lunar Curatorial Facility at the Johnson Space Center. The samples were inspected with binocular microscopes, and olivines larger than about 0.5 mm mapped on a scaled photograph of the slab. The longest dimensions of olivines were recorded. This allows us to assess the the reliability of thin sections as representative of the rock, and to ascertain whether large crystals of olivine are sporadically present.

Results: In Figure 1, we plot the grain size sequence (increasing upwards) against the MgO content of the bulk rock. There is clearly a strong correlation, with the more magnesian rocks being the coarser-grained ones, although some scatter exists. In general, this would seem to be consistent with cumulate olivine, but that is not the case here. Our analyses of two thin sections of 15555 (R in Fig. 1), for instance, show only 4.4 and 7.1% modal olivine in non-groundmass grains. This olivine is a few scattered grains with the 5 largest in ,207 averaging 1.3 mm, and the 5 largest in ,246 averaging 1.5mm in *longest* dimension. Inspection of the slabs of 15555 showed only scattered olivine grains larger than 1 mm, with the largest one about 3 mm in long dimension. Sample 15672 (M in Fig. 1) has only 8.7% non-groundmass olivine, and 15547 (P in Fig. 1) only 2.7% in the section we measured. All of the samples we have so far counted contain less than 14% non-groundmass olivine.

While some others have reported higher modal olivine contents (compilations in [13]) for some of the coarser-grained Apollo 15 olivine-normative mare basalts, we believe these are in error from the misidentification of larger pyroxene grains as olivine during point-counting. (The difference is not accountable by the small groundmass olivines). Our own analyses used back-scattered electron images to help in the identifications, and we did not use point-counts, which require rapid phase identification. In the tables of [6] for instance, where abundances as much as 28% olivine are reported, the abundances of olivine are roughly inverse to pyroxene while plagioclase remains fairly constant. If that is true it requires some special explanation. It is not apparent in bulk chemical information; the normative plagioclase/pyroxene remains constant as normative olivine varies from about 5 to 18 %.

Our analyses tend show about twice the amount of normative olivine as non-groundmass modal olivine. While some of this can be explained by the groundmass olivine, we have found that for most samples this is a small proportion of the total modal olivine. Our chemical analyses and norms agree with those of others where comparisons can be made (e.g. [1]), as do in many cases our modes (e.g. [1,14]). The amount of mesostasis in most of these basalts is small (less than 2%) and thus cannot hide olivine components. We have no obvious explanation for this discrepancy.

Figure 1. Grain size sequence v. Rock MgO. Letters designate individual samples. Sample 2 is the finest-grained, sample 25 the coarsest. Vesicular rocks have grey symbols.



We found no obvious systematic variation of the grain size of olivines among samples, despite the great variation in grain size of pyroxene and plagioclase forming the groundmass and bulk of the rock. This is true for both the thin-sections, in which the larger olivines in 15556, one of the finest-grained samples, are similar in size (~1.5 mm) to those in 15555, one of the coarsest-grained, though they are less abundant in 15556. In the coarsest-grained rocks, these olivines are smaller than most of the pyroxene crystals, and except for some of the finest-grained samples, the use of the word “phenocryst” to describe the olivines is questionable.

Olivines crystals tend to be irregular in shape, often embayed with rare euhedral-subhedral faces. Virtually all are optically zoned. Some grains are multiple, forming double or triple cores, aggregates, and rare short chains. There is no great distinction in habit among most of the samples. In the coarser-grained samples that commonly contain poikilitic plagioclase, many of the small olivines are embedded in the plagioclase and show well-developed crystal forms.

Origin of the basalts: The Apollo 15 olivine-normative mare basalts, according to both olivine mineral chemistry (see accompanying abstract by Nakamura et al.) and the petrographic features discussed here, show no sign in thin sections or in rock slabs of significant olivine phenocryst growth and settling. Chemical variation demands a separation of more than 10 % olivine to explain the sequence. The samples include vesicular rocks in both the most magnesian and most iron-rich extremes, suggesting that a range of magma compositions were extruded.

In the side of Hadley Rille opposite to where most of the samples were collected there appear to be bedded layers that might represent different thin flows, yet only two chemical groups of mare basalts were found in this vicinity. We infer that the Apollo 15 olivine-normative basalts were extruded as numerous thin flows of lavas that were related by *subsurface* separation of olivine, unlike the Apollo 12 basalts [9,10]. Many of the samples have pyroxenes and plagioclases with fairly irregular (raggedy) boundaries, suggesting prolonged subsolidus heating such as might be accounted for by burial under immediately-following flows. The essential grain-size differences among samples are not a result of such burial and subsolidus heating.

Such an inference of subsurface separation has implications for the magma plumbing systems on the Moon. Because olivine and not pyroxene is the controlling phase, such separation must have occured at fairly shallow depths in the Moon, perhaps within the crust and perhaps even in very shallow magma chambers. However, there remain significant questions. In particular, why were phenocrysts not erupted from such magma chambers (as they are in Hawaii, for instance)? And why did the more magnesian magmas cool more slowly than more iron-rich ones? One explanation of the latter might be that the magnesian lavas were the most abundant, and thus formed thicker flows. (These would be the earlier, if these basalts represent a single fractionation sequence.) Is it likely that such a process would be so regular as is required by Fig. 1?

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